Introduction to SippSteel

Introduction

Spray in place pipe (SIPP) is a trenchless technology has been narrowly used comparatively for various pipe rehabilitation applications. The wide use of SIPP technology has been limited due to its preclusion the capability to generate structurally independent linings. In most cases if the end user is going to expend the fiscal resources to rehabilitate a pipeline he or she will choose a structurally independent product. Because of the inherent SIPP issues such as the creation of an annulus, lining damages caused by host pipe failures, lining faults and the long-term creep of lining materials, current SIPP linings cannot meet the requirements of structurally independent lining. This paper introduces a new SIPP composite lining which has two interactive material layers with embedded filament reinforcement to address these critical issues therein affording a certifiably structurally independent SIPP lining.

Spray in Place Pipe Solution and Issues

Nowadays, when municipal engineers, reliability engineers, and other end users search for rehabilitation or preventative maintenance solutions for water or industrial pipes, they highly prefer a “no dig”/trenchless solution. SIPP is a trenchless rehabilitation method that utilizes both remote and robotic devices to apply thermosetting polymeric linings inside of pipe systems. The application of this method typically involves a single pass or multiple passes of equipment applying one or more polymeric material layers to form a structurally *interactive* lining. SIPP technology has several advantages compared to the other trenchless methods, such as same-day return to service, effortless service reinstatement, reduced environmental footprint, economy, market versatility and minimized community impact. Conversely, ancestral SIPP lining materials and methods have precluded these current processes from yielding structurally independent linings in pipe systems for several reasons:

- Current SIPP technologies utilize polymeric or more specifically thermosetting plastics as the structural materials, such materials yield to radial and longitudinal shrinkage during the curing process which will create an annular space/annulus between the liner and pipe. This annulus will result in hydraulic failures when pressurized fluid infiltrates behind the liner system at discontinuities.
- Typical SIPP lining materials, such as polyurea/polyurethane hybrids, polyurethanes, and epoxy systems, all possess high modulus and strength, as well as, the required rigidity. However, these materials are relatively brittle and unless applied at considerable thickness

they cannot survive internal working fluid pressure, transverse shear and overburden. The resulting requirement is then for significantly increased lining thickness which leads to a considerable increase of both labor and material costs, as well as, reducing hydraulic capacities of the pipe systems.

- When thermosetting materials are applied too thick in one pass they often tend to crack, as the increased heat from the exotherm can result in embrittlement of the lining material, increased localized stress at the lining profiles and discontinuities as well as a significant reduction in the mechanical properties of the polymer as it gets close to its glass transition temperature.
- If the rigid polymeric material is adhered directly to the pipe substrate the material shrinkage during curing can cause cracking or delamination of the lining material, especially in situations of high exotherm or mismatch in the coefficient of thermal expansions of different interfacing materials.
- If the rigid lining material is adhered to the host pipe per ASTM F3182-16 standard, the liner will not survive pipe failure events. Once fractures or remarkable deformations happen in the host pipe where the liner is adhered, the displacements on the pipe will be transferred onto the liner, causing the lining material to crack, fracture or tear due to transferred strains as shown in Figure 1.
- Current SIPP technologies are constrained to the creep failure behavior of polymeric materials under long-term continuous stress as is present in pressure pipe systems. The strength and rigidity of thermoplastic materials will initially decrease rapidly and then gradually further decrease with the time during service life which is a part of the materials nature. This defect significantly affects the application of SIPP as a structurally independent lining.
- It should also be noted that the management of lining thickness alone cannot effectively improve the lining creep resistance because of the nature of thermoplastic materials.

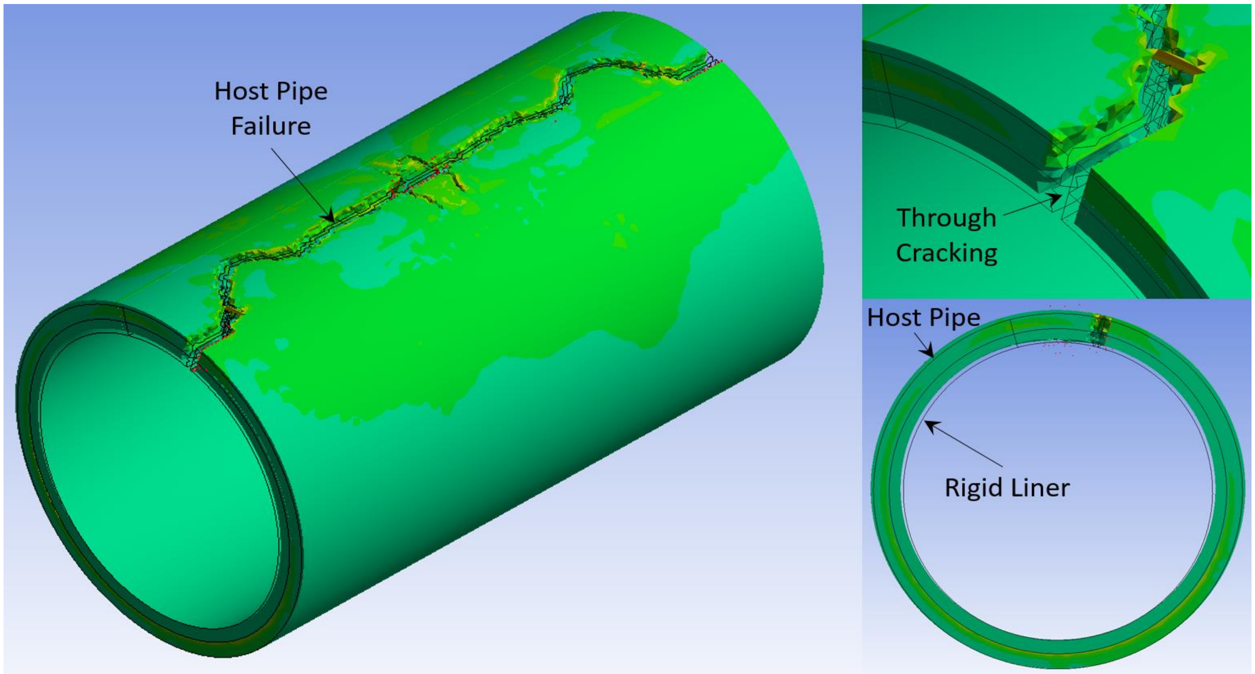

Figure 1:Liner cracking caused by host pipe failure

Filament Reinforced Composite SIPP Lining for Structurally Independent Pipe Rehabilitation

Innovative paths to SIPP technology needed to be taken to solve the problems that have precluded SIPP from being classified as structurally *independent* lining products. To make SIPP lining certifiable as a structurally *independent* lining, the liner shall closely fit the host pipe and no annulus shall be present between the lining and host pipe. Also, the liner shall possess the hoop and longitudinal strengths to resist all internal and external loading for both short-term and long-term durations. Furthermore, the lining shall not reduce the hydraulic capacity of pipe systems.

Filament reinforced composite lining is a new SIPP product that has recently been pioneered. This revolutionary solution seamlessly addresses all the issues of current SIPP technologies and provides an approach to generate structurally independent linings for a wide range of pipe systems. The composite lining is composed of two highly dissimilar lining material layers and a filament reinforcement all applied robotically in a single pass through the pipe system: *1)* a closed cell internally porous flexible layer is applied and bonded directly to the inside of a cleaned host pipe, *2)* a high tensile carbon fiber filament is helically wound and fused to the flexible layer and, *3)* a rigid layer is applied bonding to the flexible layer and encapsulating the fiber filament to form a composite lining structure.

The elastomeric layer of the composite lining is made of a low modulus, high elongation material, with low permeability. It is applied and bonded between the host pipe and rigid lining layer. Thus, the rigid polymeric layer is not adhered directly to the pipe substrate as with current SIPP technologies, but rather is adhered directly to the elastomeric or ‘flexible’ layer.

This described elastomeric has the capability to stretch and yield to absorb strains and reduce the reaction forces between the rigid liner and host pipe when pipe movement or failure events occur as shown in Figure 2. In other words, the elastomeric lining in this laminate structure allows the rigid liner to be ‘suspended’ in the host pipe so that external forces or strains are not fully transferred onto the rigid liner but are instead dissipated throughout the elastomeric layer.

Fluid infiltration in any annulus remaining between the liner and host pipe is an often misunderstood and sometimes trivialized as a problem in today’s pipeline rehabilitation industry however can be a common liner failure causation. To solve the problem, the flexible layer bonded to both the host pipe and the rigid lining layer expands due to its low Poisson’s ratio to fill and seal the annulus caused by rigid material shrinkage during the curing process. Since the elastomeric material is impermeable to pressurized liquids it prevents the fluid/gas infiltration into an annulus and avoid the potential of hydraulic failures that often occur with other trenchless technologies.

High strength filaments such as carbon fiber, have extremely high modulus, tensile strength, and creep resistance as compared to today’s unreinforced rigid SIPP lining materials. Thus, the application of these filaments in a precise helix as part of a composite lining considerably increases the lining strength and stiffness. Additionally, the described filaments share and reduce the stress on the rigid liner material caused by internal pressure or exterior buckling forces. Lower stress on the lining material significantly extends the working life of the liner against fatigue and creep failure.

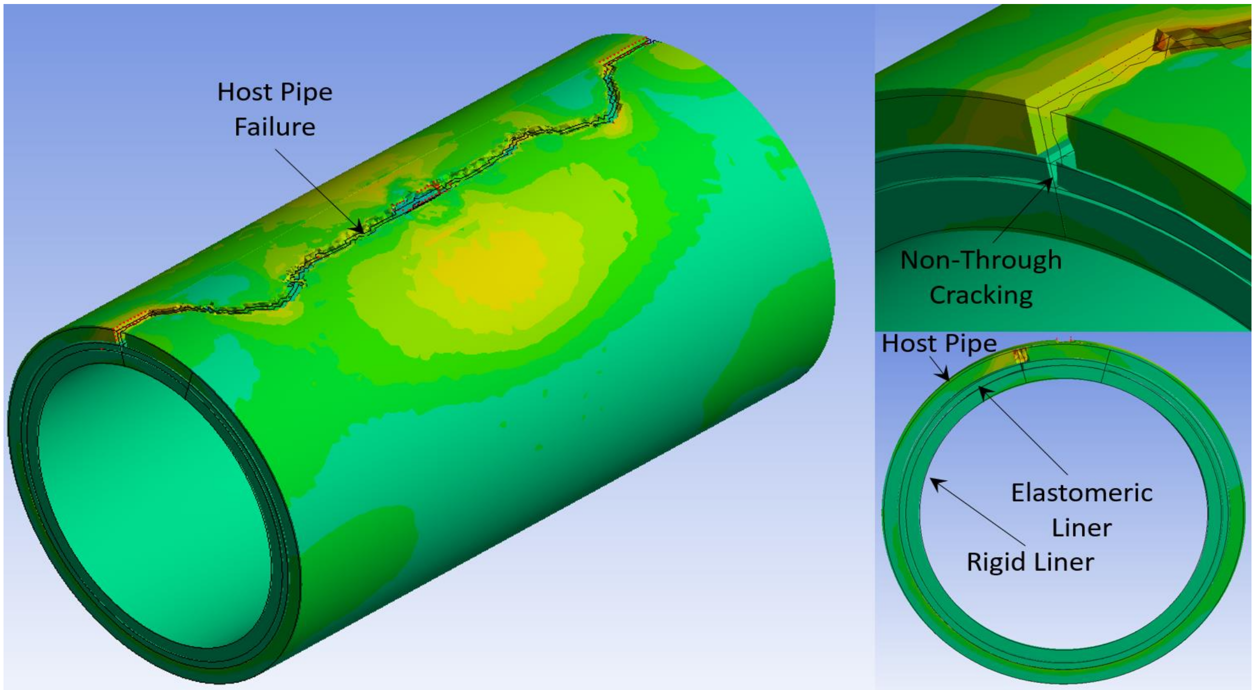

Figure 2: Elastomeric liner protect rigid liner through host pipe failure

Due to the extreme reinforcement effect of using filament in the composite lining, the requirement for the rigid lining thickness will be approximately 40~50% lower compared to thermosetting linings without filament as shown in Figure 3. One result of this innovation is that contractors can use less materials and spend shorter application time to install a new lining of significantly greater strength. This method greatly reduces the total cost of the lining, and at the same time, does not increase the reduction of hydraulic capacity caused by applying thicker linings to reach the same goal.

This filament reinforced composite lining can be used in wide range of applications, such as pressure pipes, gravity pipes, pipes working under elevated temperatures and/or fluctuating loads. The composite lining structure design is based on the pipe diameter, working condition, and optimal combination of lining thickness and dimensional filament pitch applied inside the lining. The filament pitch (distance between filament helix loops) can be adjusted based on the load. Typically, the filament pitch will be reduced to apply more filament and increase the hoop strength for the lining. In applications for exceedingly high internal pressure and/or overburden the rigid lining material can be robotically applied in multiple passes. This novel method allows the filament to be repetitively applied within the rigid material matrix to create multiple reinforcement layers. This novel approach to utilizing filament reinforcement in SIPP linings tremendously increases the strength, rigidity, and buckling resistance of the lining composite.

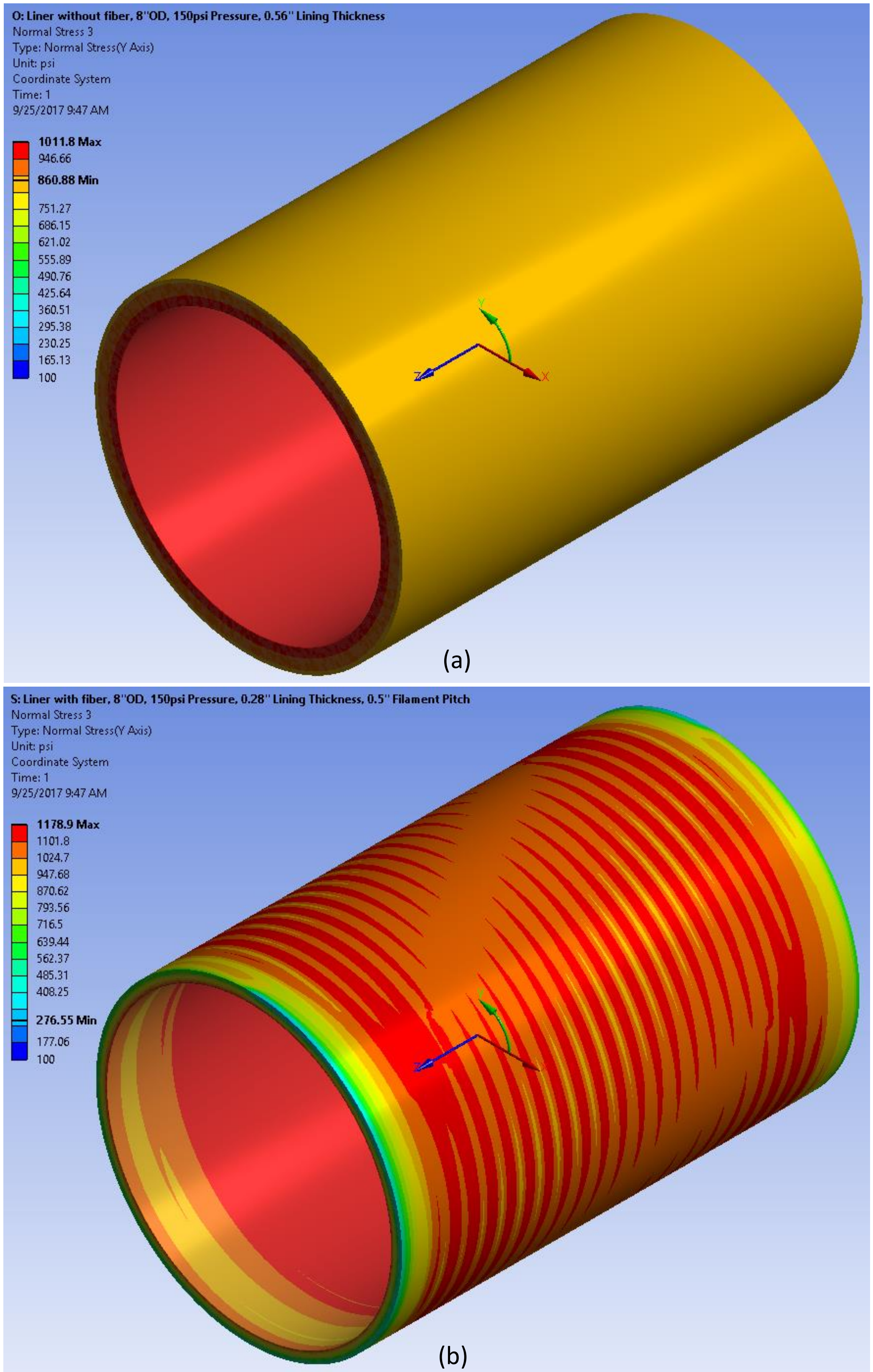

Figure 3: Stress analysis on the liners under the same 150 psi internal pressure, (a) the hoop stress on the unreinforced rigid liner with 0.56" lining thickness, (b) the hoop stress on the reinforced rigid liner with 0.28" lining thickness and 0.5" filament pitch.

The composite lining is applied via a specifically designed robotic lining system. The robotic apparatus has three interactive major segments. The back segment applies the closed cell flexible material. This material is typically applied at a thickness of 20% of the total composite cross section. The second or middle segment stores a UV resin impregnated filament which is then helically extruded on and instantaneously fused to, the flexible layer via specific wavelength UV light. The front or third major segment then applies the rigid lining material, both encapsulating the filament and bonding to the flexible layer to finalize the composition. These functionalities work together efficiently in a specific sequence to apply the composite lining in one pass through the host pipe resulting in intermolecular adhesion of the layers therein creating the highest quality composite lining.

Conclusion

A filament reinforced composite lining and robotic apparatus was introduced and highlighted by demonstrating the materials, mechanics and methods for the installation of structurally *independent* linings via SIPP technology. This underlined technology elevates SIPP practices to a new level of pipe rehabilitation with a smarter, stronger, thinner, lower-cost and safer lining product. The composite lining structure absolutely solves the inherent problems of annulus, creep failure, as well as lining failures caused by adhesion. The revolutionary idea of integrating a reinforcing filament helix significantly increases the lining strength and resistance against creep failure while reducing the required lining thickness thus significantly lessening the costs of materials, labor and time while increasing flow capacity. Finally, the composite lining is robotically applied additionally reducing costs, application times, as well as appreciably more safe and precise applications. This next generation technology invention not only is the first structurally independent SIPP lining system globally, but also initiates a revolution for the SIPP industry.

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